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International Journal of Operations and Production Management

Risk interaction identification in international supply chain logistics: developing a holistic model

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Abstract

Purpose
International supply chains can be severely disrupted by failures in international logistics processes. Therefore, an understanding of international logistics risks, or causes of failure, how these may interact with each other, and how they can be mitigated are imperatives for the smooth operation of international supply chains. This research specifically investigates the interactions between international logistics risks within the prevailing structures of international supply chains and highlights how these risks may be interconnected and amplified. A new dynamic supply chain logistics risk analysis model is proposed which is novel as it provides a holistic understanding of the risk event interactivity.

Design/methodology/approach
The paper applies Interpretive Structural Modelling (ISM) to data collected from a survey of leading supply chain practitioners, in order to analyse their perspectives of risk elements and interactions. The risk elements and their contextual relationship were derived empirically through the use of focus groups and subsequent Delphi study. The two stages of the research rely on experts' views on risk events and clusters and the level of interactions among those clusters.

Findings
A key finding of this research is that supply chain practitioner's perception of risk consists of interconnected four levels; (1) value streams risks, (2) information and relationship risks, (3) risks in international supply chain activities and (4) external environment. In particular, since Level 2 risk creates feedback loops of risks, risk management at Level 2 can dampen the amplification effect and the strength of the interactions.

Practical implications
Several managerial implications are drawn. Firstly, the research guides managers in the identification and evaluation of risk events which can impact on the performance of their international logistics supply chain operations. Secondly, evidence is presented that supports the proposition that the relationships with trading partners and LSPs, and the degree of logistics information exchange, are critical to prevent, or at least mitigate, logistics risks which can substantially affect the responsiveness of the international supply chain.

Originality / Value
The main contribution to knowledge that this study offers to the literature on SCRM is the development of a supply chain logistics risk analysis model which includes both risk elements and interactions. The research demonstrates the importance of taking into account risk interactions in the process of identification and evaluation of risk events.

Keywords – Supply chain risk management, risk analysis, risk interactions, interpretive structural modelling, international logistics

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1. Introduction

Supply Chain Management (SCM) at an international scale is more challenging than domestic SCM, primarily because international operations entail additional economic, political, competitive, cultural, operational and infrastructural uncertainties (Prater *et al.*, 2001). International supply chains also invariably include a greater number of inter-organisational relationships (Norrman and Jansson, 2004; Storey *et al.*, 2006), encompass a wider range of flows, nodes, influences, entities and transport modes, and exhibit longer lead times (Craighead *et al.*, 2007). They are consequently more vulnerable (Manuj and Mentzer, 2008) and, hence, the complexities and uncertainties inherent in international supply chain operations can significantly affect logistics control decision-making (Speier *et al.,* 2011). An understanding of international supply chain logistics risks, how these risks interact with each other, and how they can be mitigated is therefore imperative to improve operations.

Over the last three decades, Supply Chain Risk Management (SCRM) has covered three core processes, namely risk identification, risk analysis and risk mitigation. Although risk identification and analysis is considered to be fundamental to SCRM (Zsidisin and Wagner, 2010; Rotaru *et al.*, 2014) previous research has focused mostly on scattered sets of individual risks in isolation rather than taking a holistic approach to identifying and evaluating risks. However, overall risk can be amplified by the interactive combination of multiple risks. Thus contemporary supply chain risks should be analysed and modelled by incorporating the large number of potential interactions between risks generated from different supply chain stages, hierarchies and processes (see, for example, Fayezi *et al.*, 2014). While previous findings provide valuable foundations for this research, they have limited value in identifying and evaluating these multiple risk interactions (Kleindorfer and Saad, 2005; Sanchez Rodrigues *et al.*, 2010).

Furthermore, much of earlier operations management research on SCRM in logistics only examined the dyadic relationships between buyers and suppliers rather than the more complex interactions amongst all the participants in their global networks (Kembro and Selviaridis, 2015). The main contributions of this paper lie in addressing these shortcomings by focusing on the *interactions* between risk events within international supply chains, and then proposing a new logistics risk analysis model. Based on the views of experts who participated in this research, the research question is:

How can international supply chain logistics risks be understood holistically?

To best address this question, the research identifies, and then analyses, the characteristics of international supply chain logistics risks; it then examines the interactions between them. In particular, the paper focuses on the first two stages of risk management: risk identification and risk analysis. Interpretive Structural Modelling (ISM) is used to help develop a more effective understanding of supply chain logistics risks and interactions.

The paper consists of a further four sections. Section two outlines the theoretical background to the study. In section three, the steps followed in the ISM process are explained. The findings derived from the ISM-based model are presented and interpreted in section four and a new supply chain logistics risk analysis model proposed. Conclusions are presented in section five in order to highlight the theoretical and managerial implications of the research, and to suggest future research opportunities.

2. Literature review

Risk identification and analysis are both indispensable stages of risk management. Although there are a wide range of practices underpinning SCRM, most researchers agree that the SCRM process begins with risk identification and risk analysis, followed by risk mitigation (see, for example, Ritchie and Brindley, 2007; Zsidisin and Wagner, 2010; Fayezi *et al.,* 2014). The initial stage of risk management therefore is to identify as many risks as possible that can influence supply chain operations directly or indirectly (Waters, 2011). Several empirical studies have been undertaken to identify risks across various industries (Peck, 2005; Christopher *et al.*, 2011) as well as specific sectors (e.g., Schoenherr *et al.*, 2008). Chopra and Sodhi (2004) identified nine categories of risk driven by particular aspects of risk events. This process of risk identification and categorisation aims to develop a list of risks relating to general business activities as well as supply chain-specific activities, other risk categorisations can be found in, for example, Lavastre *et al.* (2012).

However, various models have been developed with the purpose of identifying and analysing risks more systematically, considering (1) organisational boundaries, (2) risk sources and (3) loss types and these are discussed below. This section categorises the SCRM models developed in the literature in terms whether or not they focus on risk identification and/or analysis and the scope of these models. A literature review was conducted to identify SCRM models published since 1995. Two groups of keywords were used: group 1 - supply chain, logistics, freight transport and supply network - and group 2 - uncertainty and risk. Selected examples of these papers are shown in Table 1.

(1) Organisational Boundaries

SCRM researchers have established classifications commonly based on organisational boundaries, which consist of internal risks, supply chain risks and external risks. From an organisation's perspective, risks are either internal or external to the organisation. Risks interconnected with their own activities are regarded as internal risks, all the rest are external risks. This categorisation is closely related to the controllability of risk events: internal risks are more controllable than external risks. In that sense, this categorisation also relates to who is responsible for mitigating risk events and defining organisational boundaries. However, categorising risks as internal or external may not capture distinctive supply chain risks and other studies such as Schoenherr *et al.* (2008) assess supply chain risks separately.

Table 1 here

(2) Risk Sources

Other models are in accordance with supply chain processes and functions, which is the most common classification as judged by SCRM researchers. These processes and functions are the sources where risks may arise. Mason-Jones and Towill (1998) argue that causes of uncertainty are to be found on the supply side, in manufacturing processes, on the demand side and, most notably, in control systems that overarch the other three areas. An example of

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each classification of risk could include supplier bankruptcy (e.g. GT Advanced a main supplier to Apple which filed for bankruptcy in 2014), production problems (e.g. Mars Group in 2016 identified foreign bodies in chocolate stemming from their manufacturing processes, which led them to recall confectionery distributed to 55 countries), the emergence of new channels to market (e.g. the rise of online / omni-channel in the retail sector), and internal corporate governance issues (e.g. Tesco who overstated their profits in 2014 / 2015). As disruption risks, natural disasters and security risks emerged from environmental change and terrorist events Christopher and Peck (2004) added environmental risk to possible risk sources (e.g. Japanese tsunami, 2011). Their model assumes three main parties in the supply chain, namely supplier, focal company and customer, and then demonstrates the location where these five risks will arise. Except for the 'control' systems overarching all SCM activities, each source relates to a distinctive activity area and generates idiosyncratic risks.

(3) Loss Types

Another method of classification categorises the types of loss that supply chain risks can cause. SCM is generally defined as "the management of material, information and financial flows through a network of organisations that aims to produce and deliver products or services for the consumers" (Tang, 2006: 453). From this perspective, disruptions to material, information and finance flows generate risks, thereby threatening and implicitly reducing the value that can be derived from SCM. Focusing on the importance of value in SCM, some researchers classify risks according to types of loss in relation to 'flows' or 'values'. The most common losses, proposed by SCRM researchers are material, financial, information and time (Tang and Musa, 2011).

SCRM research rarely goes beyond exploring risks and providing typologies or taxonomies for identified risks. Despite the fact that a risk event is often triggered by other risks, analysis of the relationships between those sequential risks is seldom carried out. Although studies which focus on risk categorization have provided valuable insights into identifying and understanding risk events, research on risk identification has generally not considered the interactions between risk clusters. Mason-Jones and Towill (1998) also highlight the importance of including interactions among risk events when undertaking risk assessments and argue that effective uncertainty reduction in supply chains can be achieved by understanding and tackling the root causes of risk events in the four identified risk areas. Peck (2005) also suggested that supply chain practitioners struggle to explain risk as multi-dimensional constructs as they are pre-occupied with reacting to, or solving, difficulties rather than examining the intricacies of the causal chain. Similarly, Chopra and Sodhi (2004) expressed the difficulties of SCRM due to the interconnections between individual risks.

In this respect, supply chains offer a holistic risk structure, with hierarchies and interconnections, embracing risk interaction, systematic risk identification, cause-and-effect and failure mode analysis. These can provide clues for strategic risk management once they are understood thoroughly (see, for example: Sanchez-Rodrigues *et al.*, 2010; Ghadge *et al.*, 2013). Elsewhere, Peck (2005) proposed four levels of vulnerability: value stream/product process; assets and infrastructure dependencies; organisations and inter-organisational networks; and environments. This paper uses ISM to develop a dynamic supply chain logistics risk analysis model in order to better understand both risks and their interactions. In particular the research focuses on the root cause of risk amplification within the risk structures that may jeopardise supply chain operations. Supply chain risks often create a risk spiral (Christopher and Lee, 2004), and breaking this spiral requires a holistic understanding of risk structures. In light of this the key questions that guide this research are: which risks in the international logistics supply chain interact with each other; what are the root causes of sequential risk interaction; and, how are risk interaction spirals broken?

3. Methodology and Results

ISM can be used to identify the structure of complex relationships among elements related to a particular research problem. It can help in understanding a complex system by considering the hierarchy and relationships among elements of the system (Sage, 1977). ISM was used in this research to identify and evaluate interactions among the possible risk elements in global supply chain logistics. The findings present a graphical structural map of elements, highlighting the causal connections of elements and solutions for complicated risk issues in global supply chains and the most critical risk areas requiring mitigation. In SCRM research, Faisal *et al.,* (2006) used this method to construct structural models of risk mitigation enablers, and of supply chain risk events respectively. However, the value of previous studies has been limited by the fact that the suggested risk factors were not scientifically derived. This research adopts a more rigorous methodology than these earlier studies by adopting a process to collect empirical data about risk elements and their contextual relationships from industry experts.

ISM typically comprises seven steps (Faisal *et al*., 2006) although Govindan *et al.* (2012) recommend one further step to check whether the ISM model has any conceptual inconsistency requiring modification. This research uses the seven steps and checks the validity and implications in the discussion section.

Step 1. Identifying the Elements for Analysis

The initial stage of the ISM process determines the elements constituting the complex system to be investigated. In this study, the risk elements emerged from the discussions of six parallel focus groups formed from 30 practitioners, each with more than 7-years industry experience, and 6 academics who had previously worked in managerial roles in the industry. The practitioners were purposively selected to incorporate exporters, importers, freight forwarders, and Logistics Service Providers (LSPs) to capture the most significant global supply chain logistics risks from diverse perspectives. The focus group method is an effective way of generating ideas from a group of experts in a specific subject area and of triangulating their perceptions of a specific research phenomenon (Robson, 2002). In SCRM research, Pettit *et al.* (2010) and Sanchez-Rodrigues *et al.* (2010) primarily used this method to identify risks in supply chains and in transport respectively.

Each focus group started with a free discussion about the experiences of participants concerning disruptions to international logistics operations. Participants were then asked to generate a list of international logistics risks and to categorise them into risk clusters. These risk clusters encompassed risks stemming from the external environment, from LSPs, from trade partners and from the control system as well as from issues relating to time, cost and product. For the purpose of undertaking an unbiased analysis each risk element was allocated a number from 1 to 20 (Table 2).

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Table 2 here

Step 2. Contextual relationships between Risk Pairs

In step 2, the contextual relationships between risk pairs were examined in order to determine the pairwise relationships between risk elements. A two-stage process was followed whereby two groups of participants, selected from the focus groups in consideration of their roles and titles relating to risk management, conducted the first and second stages of this process. The participants were asked to make decisions on the contextual relationships between two risk clusters. The contextual type of "leads to" was selected to constrain the relationship to direct effects. As a unified opinion on the relationship is required to develop an ISM-based model, a Delphi study was adopted as the third stage to refine ideas and to determine a consensus among six participants who each had over 7-years industry experience associated with risk management and customer service. The detailed process of Step 2 is described in Table 3 and shown in Figure 1.

Table 3 here

Figure 1 here

The 20 risk elements generated 190 suggestions for pair-wise relationships. The participants in Group A and Group B discussed the relationships between element *i* (1 to 20) and element *j* (1 to 20) on a pairwise basis, and allocated arrows to denote the direction of cause and effect between each pair of elements. In the first round, 96 relationships showed discrepancies between the views of Group A and Group B. The two groups subsequently presented written statements regarding the reasons for their decisions about these discrepancies. After exchanging written statements with each other, the two groups amended their initial ideas with the discrepancies persisting for only 23 relationships. The 23 discrepancies were assessed by four industry experts in a Delphi panel. The experts were requested by email to provide observations about the 23 relationships. The answers were later shared across the panel during four rounds of written responses, after which a consensus among panel members was reached concerning the pairwise interrelationships among the 20 risk elements. In order to address the danger of reflexivity, or the possible influence of the interviewer, or the interview environment, on the interviewee relationship, care was taken to ensure that the operation of the panel was conducted entirely objectively, uninfluenced by the presence of the researcher or other possible extraneous influences (Finlay, 2002).

The study could have suffered from common method bias arising from practitioners taking part in both stages of the two-stage research approach while representing a single organisation and its supply chain, with the results relying to a certain degree on their individual views. In order to avoid this problem the study was run in two stages and data triangulation applied in a sequential fashion. Furthermore, the selection criteria of participants who contributed to the focus group and ISM stages included the experience of participants as a key characteristic. By using a series of Delphi Panels in the initial step of the ISM analysis the potential for bias from the views of individual group members was reduced.

Step 3. Developing a Structural Self-Interaction Matrix

The contextual relationships were summarised into one Structural Self-Interaction Matrix (SSIM) by assigning one of the following four symbols to an (*i*, *j*) entry.

V: element *i* leads to element *j*;
A: element *j* leads to element *i*;
X: elements *i* and *j* cause each other;
O: elements *i* and *j* are not related at all.

Eight industry experts examined the list of contextual relationships between elements and, using the cause and effect arrows of the participants from stage 2, the interconnections were converted to entries in an SSIM matrix as shown in Table 4.

Table 4 here

Step 4. Developing a Reachability Matrix

Given the SSIM, a reachability matrix was developed by filling each (*i, j*) entry with 0, 1 or 1* according to the following rules:

- 0: element *i* does not cause element *j* and there is no transitivity between them;
- 1: element *i* directly causes element *j*;
- 1*: there is transitivity between *i* and *j* by the mediation of another element.

After the initial reachability matrix of direct relationships was completed, the final reachability matrix was developed by taking transitivity into consideration. Transitivity can be checked by considering any indirect relationships among elements: if element *i* causes element *j* and element *j* also results in element *k*, the transitivity is confirmed between element *i* and element *k* due to their indirect relationship mediated by element *j*. In this case, the transitivity was incorporated into the final reachability matrix by assigning 1* to the relationship, and zero values were removed. *Driving power* and *dependence power* can be also computed in this matrix. *Driving power* is the total number of elements (each including itself) which affects other elements, while *dependence* is the total number of elements, which are affected by other elements.

However, the initial reachability matrix had to be refined because several risk elements generated excessive transitivity, leading to the matrix containing too many indirect relationships, which, in turn, led to the driving power and dependence of most elements to be at a maximum. Excessive transitivity, caused by indirect relationships among risk clusters, was found in risk clusters associated with the inter-organisational relationships as well as control systems risks, namely, Conflicts between trade partners (8), Dependency upon LSPs (16), Failure in logistics control (17), and Failure in information exchange (18).

Contrary to other risk elements that have a definite time-frame for their occurrence and realisation, these four elements retain their unique characteristics and can occur at any time during the entire logistics operation, thus making risk situations worse. For these elements the temporal sequence of risk events sometimes reverses with no clear reason, generating numerous feedback loops and interconnecting a majority of the elements. It was thus decided to eliminate these four elements from the analysis, so that interconnections between the remaining 16 elements could be identified in the reachability matrix, as shown in Table 5. Instead, the four risk elements excluded from Step 4, 5 and 6 were incorporated into the final structural model in Step 7 in order to fully explore their roles in international logistics operations and global SCM.

Table 5 here

Step 5. Level Partitioning

Level partitioning was then conducted given the final reachability matrix. First of all, the reachability set (RS*i*), antecedent set (AS*i*) and intersection set (RS*i* ∩ AS*i*) of each element are found. The elements of the top level, whose reachability set were the same as its intersection set, needed to be found and set aside. The new reachability set, antecedent set and intersection set of each element were then created given the remaining elements. The elements of the 'next top level' were chosen by checking whether the reachability set was equal to the intersection set. This process was continued until all elements were partitioned into levels.

Once Level partitioning had been conducted on the basis of the final reachability matrix of 16 elements, and after checking the reachability set and the intersection set, four risk elements were chosen for the top level: Trade settlement issues (6), Additional costs at destination (13), Cargo loss and damage (19) and Delay (20). After removing these four elements, new reachability, antecedent and intersection sets were generated, and Product discrepancy (9) and Freight rate fluctuation (12) were selected for the second level. It is interesting to note that these six elements were all directly linked to the three types of losses found in the focus groups, although some of them, such as freight rate fluctuation and additional costs at destination, were also associated with risks emanating from trade partners and LSPs.

The subsequent rounds took the 10 remaining elements into account. Faulty equipment (14) was recognised as the sole element of the third level whereas removal of Faulty equipment (14) led to Shortage of space and containers (11) and Inland operational disturbances (15) was assigned to the fourth level. The risk elements associated with trade partner and logistics service provider risks were also partitioned, even though there were several hierarchies among them. The risk elements relating to the external environment, such as Economic instability (1), Export/Import regulations (2), Natural disasters (3) and Human-derived disruptions (4), comprised the lowest level in this partitioning process. The results are shown in Table 6.

Table 6 here

Steps 6* and *Step 7. Drawing a directed graph (or digraph) and an ISM-based model

From the reachability matrix and the partitioned levels, a digraph was drawn using nodes and arrows. At this stage, transitivity was not taken into account because a series of arrows can sufficiently represent any indirect relationships. After being arranged vertically and horizontally according to the levels, risk elements were linked by arrows based on the reachability matrix.

The final ISM-based graph was drawn by replacing the node numbers in the digraph with the original names of the elements. The ISM-based model demonstrates the hierarchical structure of risks in international logistics and highlights their interrelationships with the dependence and driving power of risk elements.

A digraph was generated by arranging the 16 elements according to the partitioned level and by connecting the elements according to the final reachability matrix. The digraph was later developed into an ISM-based model by substituting element numbers from the final reachability matrix with the original names used to describe risk clusters, as shown in Figure 2. The ISM analysis demonstrated that most risk clusters related to types of risk losses interacted with each other except for product discrepancy and freight rate fluctuations. Also, the analysis showed that there was a clear division between trade partner and LSP risks, although these two risk groups eventually interacted at the highest level. The external environment risks occupied the bottom end of this model, since this risk pattern influenced most of risk clusters. In this respect, the final model confirmed that risk clusters had firm contextual characteristics because, when minor causalities were ignored, risk events categorised under the four risk patterns found in the study (namely losses, logistics service provider, trade partner and external environment risks) had frequent interactions with each other.

Figure 2 here

When the analysis considered the four risk elements (Conflicts between trade partners (8), Dependency upon LSPs (16), Failure in logistics control (17), and Failure in information exchange (18) that were initially excluded from Step 4, the risk structure became more dynamic. Compared to Figure 2, which clearly suggests a hierarchical structure of risks with one-way relationships from bottom to top, these four risk elements generated numerous feedback loops with moderating impacts on the scale of losses being incurred as a result of risks in international supply chain activities, as shown in Figure 3. The excessive transitivity found in the ISM was largely due to the numerous feedback loops by these four elements, which play a pivotal role in turning even a low-impact risk event into a severe disruption with subsequent impacts. These four risk elements were also all interconnected with each other, thus their dynamic interactions amplified significant transitivity. The levels in Figure 3 are discussed further in the following section.

Figure 3 here

4. Discussion

The research set out to address the question: how can international supply chain logistics risks be better understood by adopting a more holistic lens? This was addressed empirically by identifying and analysing a wide range of risk elements occurring in international supply chains logistics and postulating a structure for those risk elements and the multiple interactions which may occur. In international supply chains, a given disruption or disturbance can generate other risk events which can amplify the impact of the original disruption or disturbance, creating a loss type which in turn causes other losses. Thus risks cannot solely be envisaged as stand-alone events, but rather form part of an inter-linked network of risk occurrences and impacts.

Research on supply chain vulnerabilities has been extensive (see, for example, Norrman and Jansson, 2004; Pereira *et al.*, 2014). According to the findings from ISM analysis here, in practice several parallel hierarchies of risks are generated across multiple stages of the supply chain. These hierarchies are similar to those proposed by Peck (2005) but also exhibit several differences. The most important finding is that individual risks and their hierarchies are closely inter-related; this is in line with the characteristics of supply chains which are inter-connected and inter-dependent, thus resulting in the presence of considerable complexity across the supply chain nodes and links which are prone to disturbance and disruption (Tatham and Christopher, 2014). The risk structure developed from this study shows that logistics practitioners perceive four distinct ***levels*** of risk, which were formulated in the ISM-based modelling process, being Level 1 – Value streams risks, Level 2 – Information and relationships risks, Level 3 – Risks in international supply chain activities, and, Level 4 – External environment risks (see Figure 3). The risk spiral referred to by, for example, Mason-Jones and Towill (1999) and Christopher and Lee (2004), has also emerged in this model as a series of self-enhancing loops around Level 2 risks. Each level is discussed below.

Level 1 (Value Streams risks) consists of risks consequences that are related to the metrics of international supply chain practice. Practitioners tended to consider time, cost and quality of product as the main metrics. ***Delay*** is the deviation from the target delivery time; ***Trade settlement issues, Freight rate fluctuation*** and ***Additional costs at destination*** can increase the targeted maximum logistics cost and ***Product discrepancy*** and ***Cargo loss and damage*** are related to unanticipated product quality failures. These findings are in line with what Kearney (1999) and Norrman and Jansson (2004) found, namely supply chains are influenced by deviations in time, cost and quality; hence any damages to these three types of failures are effectively labelled as risks by managers. These risks are at the top of the hierarchy and are dependent on, or derived from, risk events in the lower levels, but they still influence Level 2 risks. Although information is a critical value stream in SCM, it would be more appropriate in SCRM research to place it at Level 2, because it is a trigger or enhancer of risk events rather than a risk effect.

Level 2 (Information and Relationships risks) is related to information flows and inter-organisational relationships commonly found in global supply chain logistics networks. This level is significant as a generator and facilitator of various risks. In organisational information processing theory (Galbraith, 1973), risk is derived from the gap between information processing needs and information processing capability. The magnitude of risks grows if information processing needs rise or information processing capability is reduced. When a disruption or disturbance occurs, in order to be able to manage the unexpected event and to adjust the logistics system, the need for information processing increases. In international supply chains, however, information is often derived from multiple entities because the logistics operators' partners produce, process and provide a considerable proportion of the information required by the logistics operator. Moreover, as a consequence of logistics outsourcing and global sourcing of products, firms need to rely on the information processing capacity of other entities. A close relationship with trade partners and LSPs is vital for narrowing the gap between information processing needs and information processing capability. An effective risk management system, therefore, must include effective information sharing and effective relationships among decision-makers so that a single risk event does not trigger other risks caused by information distortion (Bode *et al.*, 2011).

This Level also embraces several risk clusters that were excluded from the initial ISM procedure, since they generated a significant number of indirect causal relationships among risk elements. These are contractual risks (***Conflicts with trade partners*** and ***Dependency upon LSPs***) and information/control risks (***Failure in information exchange*** and ***Failure in logistics control***). As shown in Figure 3, they play a pivotal role in mediating risks generated by numerous feedback loops and interconnections among risks. In order to break the risk spiral in supply chains, Christopher and Lee (2004) argue supply chain visibility and control can be improved through supply chain collaboration. This finding is consistent with the findings obtained from the ISM-based model developed through this research. According to the model, seamless information flows and control of supply chains can be achieved through close collaboration among supply chain entities, so this level of risk can be mitigated.

Level 3 (Risks in International Supply Chain Activities) risks include all the risks that stem from the logistics activities of organisations and physical and ICT infrastructure required to plan and run international supply chain networks. It combines Level 2 and part of Level 3 of Peck's model (2005) as it encompasses tangible assets and infrastructure as well as organisational links and nodes. Risks at this level can be influenced by Level 4 but impact on Level 1. They can interact with Level 2 creating feedback loops which may aggravate risk events. From the ISM model, risks relating to activities in international logistics can be separated into two types: activities between trade partners and, activities centred on LSPs. Activities for which the trade partner is responsible are ***Inaccurate documentation*** and ***Cargo loading issues***. Conversely, four risk elements were generated exclusively from LSP activities, namely ***Vessel operation disturbances, Inland operation disturbances, Shortage of space and containers*** and ***Faulty equipment***.

Further, the supplier, the customer and the LSP form a mutually-dependent logistics triad. In the context of risk management for international supply chains the effective assignment of responsibilities and accountability associated with risk prevention and mitigation is undertaken among logistics triad members. Furthermore, the logistics triad extends to include several intermediaries such as freight forwarding companies, export/import agencies, customs offices and port/terminal operating companies. This complex web of organisations can make risk identification and mitigation more challenging than in the case of risk management in a typical domestic logistics triad.

Four **Level 4 (External Environment)** risk elements: ***Natural disasters, Human-derived disruptions, Economic instability*** and ***Export/Import regulations*** were identified. These elements are difficult to control and some of them may be anticipated but cannot be completely avoided or mitigated at a firm or supply chain level. They include natural, social, political and macro-economic disruptions, which may be affected severely by other factors within the supply chain. These risk elements reside in the lowest level of the risk structure hierarchy. The risks categorised under Level 4 are clearly differentiated from operational risks (see, for example, Tang, 2006).

As Hausman *et al.,* (2005) suggest, global trade activities that generate the need for international logistics are known to be comprised of 'logistics flows' and 'commercial flows'. Logistics flows consist of the physical distribution of goods from exporter to importer, whereas commercial flows comprise the flow of funds between companies linked either to

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the physical distribution process or to indirect cost items generated by overheads and administration activities. Regarding the impacts of external environment risks on these two flows, ***Natural disaster*** and ***Human-derived disruptions*** are closely related to logistics flows, while ***Economic instability*** and ***Export/Import regulations*** (or any policies at governmental or inter-governmental levels) are associated more closely with commercial flows. ***Economic instability*** may negatively affect the overall availability of logistics provision by influencing the volume of cargo traded, but its impact on the logistics flow is limited compared to its impact on the commercial flow.

The ultimate purpose of risk identification and analysis is to decide the priorities for risk management. The ISM-based model shows the transition of one risk to another, for example, from Level 4 to Level 3, or from Level 3 to Level 1. The risks at Level 3 and 4 are often considered to be low-frequency and high-impact disruptions (Tang, 2006). The main reason for the high impact generated by risks from these levels may be attributed to the interactions among these risks generated through knock-on effects. As a result, mitigating all levels of risks via the application of proactive and reactive measures is critical for firms to minimise the initial risk impacts arising from individual risk elements (Luo and Yu, 2015). Various risk mitigation strategies can be considered as countermeasures to these risks, so supply chain logistics capabilities such as flexibility, agility and adaptability can make the supply chain more robust and resilient. Controlling and minimising risks generated from Level 1, Level 3 and Level 4 should be among the main objectives of effective risk management systems.

Sheffi and Rice (2005) argue that supply chain disruptions can generate small initial impacts followed by very severe subsequent impacts. The ISM analysis found that international supply chain risks can be amplified by risks categorised as Level 2, linked to deficiencies in information and control systems. Therefore, risks originating from Level 2 can be considered as the main driver of subsequent impacts which continue to create feedback loops of risks among Level 1, 2 and 3 unless adequate measures are taken to break this risk spiral generated by dynamic risk interactions. Risk management at Level 2 can dampen the amplification effect and the strength of the interactions. It can effectively eliminate, or subdue, the subsequent impacts of a disruption; hence having effective information and control systems can minimise the response and recovery time operations have after a disruption. This finding provides strong evidence as to why relationship building and information processing should be prioritised in global supply chain and logistics management where a great number of entities can contribute to the distortion of information.

5. Conclusions

Recent SCRM literature provides a number of useful models which have been used to identify or analyse risks affecting supply chain performance (Table 1). Here, however, a more comprehensive model applicable to risk management in international supply chain logistics is developed. While, for example, Kleindorfer and Saad (2005) and Peck (2005) provide valuable foundations and insights for this research, the strength of this study is the deployment of a more robust methodological approach, with the adoption of ISM facilitating the measurement of interactions among risk elements.

A key finding of this research is that supply chain practitioners' perception of risk is derived from: the source of the risk, the level at which it occurs and the nature of subsequent risk. The research demonstrates that the initial impacts of a risk element affect several risk levels: Level 2, Level 3 and Level 4. The interactive impacts of risks at these levels, in turn, all finish at Level 1. Subsequent impacts are created by Level 2 risks which amplify two-way

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interactions among risks at Levels 1, 2 and 3. Risk management should therefore be implemented at all Levels. In addition to this, a focus on managing Level 2 risks is an effective way of dampening the subsequent impacts of, for example, a supply chain logistics disruption. The total impact, and the duration of a disruption, can thus be minimised. These findings provide strong evidence of the need for careful relationship building and effective and robust information processing in international supply chains. This is particularly important as international supply chains are complex networks and are comprised of a number of organisations of varying size and power. Information distortion is therefore a significant source of risk. Thus effective risk management at operational and tactical levels is crucial for the minimisation of both risk and risk impacts at other levels.

This research contributes to SCRM literature through the development of a supply chain logistics risk analysis model which includes risk elements and interactions. The empirical research presented above shows that a better understanding of root causes among risk events can be achieved through effective risk identification and analysis, so decision makers can prioritise risk events prior to setting mitigation strategies. The research demonstrates, empirically, the importance of breaking the risk spiral, suggested by the conceptual research of Mason and Towill (1999) and Christopher and Lee (2004). It also integrates the supply chain and logistics domains by investigating risk management strategies to find out how risks generated from the logistics network can affect the overall performance of the supply chain. Our paper also presents the application of ISM, a robust analytical methodology, to measure the interactions between risks, so the holistic model derived from the research can be used as the starting point for setting supply chain risk mitigation strategies. Moreover, the risk elements and their contextual relationships were derived from industry experts, which distinguishes this holistic model from other conceptual models of risks in extant studies. The model demonstrates the importance of taking into account risk interactions in the process of identification and evaluation of risk events.

This study generates several promising future research directions, which are outlined as follows:

- Interpretive Structural Modelling generally involves interpretation of a complex system at three stages: selection of elements, their contextual relationships and the discussion of the proposed model. This research adopted as robust a method for this interpretation as possible, using focus groups and panel discussions. Post-hoc validation of the model using case studies or a large-scale survey would also be beneficial for generalising this interpretation.
- The model developed in this research could be more widely tested in other geographical areas or business risk situations, e.g. by means of comparative studies, so that findings can be generalised with greater confidence. A large-scale survey measuring the relationships among the identified risks across different types of global supply chains, covering a wide variety of suppliers and buyers located in different countries, different types of cargo and a balanced mix of developing and developed countries, would test and refine the model. Further, the identified risk interactions could be assessed by applying OR methods to measure the impact of the sequential and parallel paths of risks in order to guide decision-making on the degree of priority of each risk path and their main root causes. Application of the model to different geographical, supply chain and sectoral contexts would allow sensitivity analysis on the refined model to be conducted.
- The model can be extended to cover specific supply chain risk mitigation strategies

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which can be applied to respond to risk events occurring within each of the four levels, incorporating risk mitigation strategies derived from previous studies highlighted and discussed above. In order to extend the model, the main input, output and moderating variables affecting the performance of logistics networks and global supply chain need to be identified from previous OR research on supply chain risk interactions. OR modelling-based research could also be undertaken to measure the effects of risk mitigation measures on the output variables which reflect better the performance of global supply chains, e.g. lead-time reliability and variance, running costs, stock at source and market, CO_2 emissions and product waste.

- The risk assessment techniques developed in this research can be used to prioritise risks based on their estimated likelihood and impact. Such an assessment can incorporate risk interactions so that risk evaluation becomes more holistic and dynamic. Advanced risk measurement techniques could be applied to a range of case study settings, such as Data Envelopment Analysis and Analytical Hierarchical Process, to measure the effects of risk interactions forming each of the risk paths, and the overall effects of each risk path on supply chain performance.

Several managerial implications can be drawn from this study. Firstly, the research can guide managers in the identification and evaluation of risk events which can impact on the performance of their global supply chain logistics operations. The interactive risk structure derived from the research can assist managers in identifying the root causes of their current and future disruptions. It can also aid strategic decision-making around investments made in future supply chain logistics risk management programmes. Secondly, this study emphasises that the relationship with trading partners and with LSPs, and the degree of logistics information exchange, are critical to prevent or at least mitigate logistics risks which can substantially affect the responsiveness of global supply chain logistics.

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Table 1. Examples of Papers Developing Risk Identification and Risk Analysis Models

Author (Year)	Risk Identification			Risk Analysis	
	Org. Boundaries	Risk Sources	Losses Types	Measurement of individual Risk	Risk interactions considered
Mason-Jones & Towill (1998)		X			
Zsidisin (2003)	X				
Tang (2006)		X			
Waters (2007)	X		X	X	
Manuj & Mentzer (2008)		X			
Schoenherr *et al.* (2008)	X			X	
Sanchez-Rodrigues *et al.* (2010)		X			X
Zsidisin & Wagner (2010)	X				
Christopher *et al.* (2011)		X			
Tang & Musa (2011)			X		
Ghadge *et al.* (2013)		X	X	X	X
Leat & Revoredo (2013)		X	X		

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Table 2. The 20 derived risk elements

No	Risk Elements	No	Risk Elements
1	Economic instability[1]	11	Shortage of space & containers
2	Export/Import regulations	12	Freight rate fluctuation
3	Natural disasters	13	Additional costs at destination
4	Human derived disruptions[2]	14	Faulty equipment
5	Inaccurate documentation	15	Inland operational disturbances
6	Trade settlement issues	16	Dependency upon LSPs
7	Cargo loading issues	17	Failure in logistics control
8	Conflicts between trade partners	18	Failure in information exchange
9	Product discrepancy	19	Cargo loss & damage
10	Vessel operational disturbances	20	Delay

[1] e.g. product price change
[2] E.g. strike, port congestion, terrorism, piracy, social unrest

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Table 3. Step 2 Participants and Process

	Participants
(1) Group A	Including e.g. Carrier (Manager, 7-year experience); Researcher (PhD, 8-year experience)
(2) Group B	Including e.g. Exporter (Manager, 11-year experience); Freight Forwarder (Director, 14-year experience)
(3) Delphi Panel	Including e.g. Exporter, Importer, 3PL Provider, Carrier (Managerial level with more than 7-year experience)
	Process
Round 1	(1) Group A decides the contextual relationships between two elements. (2) Group B decides the contextual relationships between two elements.
Round 2	(1) If there are discrepancies in the decisions, Groups A and B produce a written statement regarding the reasons for their decisions in respect of the discrepancies (2) After exchanging the written statements, Groups A and B make their final decision on the pairwise relationships.
Round 3	(1) If there are still any discrepancies, the members of the Delphi panel review the relationships until they reach a consensus. (2) The decisions on the contextual relationships among the risk elements are finalised.

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Table 4. Structural Self-Interaction Matrix (SSIM)

		j																			
i		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	1		A	O	O	V	V	V	V	V	O	V	V	V	O	O	V	V	O	O	O
	2			O	O	V	V	O	V	V	O	O	O	V	O	V	V	V	V	O	V
	3				O	O	O	O	O	O	V	O	O	V	V	V	O	V	V	V	V
	4					O	V	O	V	O	V	V	V	V	V	V	V	V	V	V	V
	5						V	V	X	V	O	O	O	V	O	V	O	O	X	O	V
	6							O	X	O	A	O	O	V	O	O	O	O	A	O	X
	7								X	V	O	O	O	V	O	V	O	V	A	V	V
	8									X	A	A	A	X	A	A	A	A	X	A	X
	9										O	O	O	O	O	O	O	V	A	O	V
	10											O	O	V	O	V	O	V	V	V	V
	11												V	O	V	O	X	V	X	O	V
	12													O	O	O	X	V	V	O	V
	13														A	A	O	A	A	A	X
	14															O	O	V	O	V	V
	15																A	V	X	V	V
	16																	X	X	O	X
	17																		X	A	X
	18																			A	X
	19																				X
	20																				

Key: V: element *i* leads to element *j*; A: element *j* leads to element *i*; X: elements *i* and *j* causes each other; O: elements *i* and *j* are not related at all.

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Table 5. The Final Reachability Matrix of 16 Risk Elements

	1	2	3	4	5	6	7	9	10	11	12	13	14	15	19	20	**Driving Power**
1	1	0	0	0	1	1	1	1	0	1	1	1	1*	1*	1*	1*	12
2	1	1	0	0	1	1	1*	1	0	1*	1*	1	1*	1	1*	1	13
3	0	0	1	0	0	1*	0	0	1	0	0	1	1	1	1	1	8
4	0	0	0	1	0	1	0	0	1	1	1	1	1	1	1	1	10
5	0	0	0	0	1	1	1	1	0	0	0	1	1*	1	1*	1	9
6	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1*	1	4
7	0	0	0	0	0	1*	1	1	0	0	0	1	1*	1	1	1	8
9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2
10	0	0	0	0	0	1	0	0	1	0	0	1	1*	1	1	1	7
11	0	0	0	0	0	1*	0	0	0	1	1	1*	1	0	1*	1	7
12	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2
13	0	0	0	0	0	1*	0	0	0	0	0	1	0	0	1*	1	4
14	0	0	0	0	0	1*	0	0	0	0	0	1	1	0	1	1	5
15	0	0	0	0	0	1*	0	0	0	0	0	1	1	1	1	1	6
19	0	0	0	0	0	1*	0	0	0	0	0	1	0	0	1	1	4
20	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	4
Degree of Dependence	2	1	1	1	3	14	4	5	3	4	5	14	10	8	14	16	

0: element *i* does not cause element *j* and there is no transitivity between them; 1: element *i* directly causes element *j*; 1*: there is transitivity between *i* and *j* by the mediation of another element.

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Table 6. Level Partitioning Results

No	Reachability Set (RS)	Antecedent Set (AS)	Intersection Set (IS)	Level
1	1,5,6,7,9,11,12,13,14,15,19,20	1,2	1	**7**
2	1,2,5,6,7,9,11,12,13,14,15,19,20	2	2	**8**
3	3,6,10,13,14,15,19,20	3	3	**7**
4	4,6,10,11,12,13,14,15,19,20	4	4	**7**
5	5,6,7,9,13,14,15,19,20	1,2,5	5	**6**
6	6,13,19,20	1,2,3,4,5,6,7,10,11,13,14,15,19,20	6,13,19,20	**1**
7	6,7,9,13,14,15,19,20	1,2,5,7	7	**5**
9	9,20	1,2,5,7,9	9	**2**
10	6,10,13,14,15,19,20	3,4,10	10	**5**
11	6,11,12,13,14,19,20	1,2,4,11	11	**4**
12	12,20	1,2,4,11,12	12	**2**
13	6,13,19,20	1,2,3,4,5,6,7,10,11,13,14,15,19,20	6,13,19,20	**1**
14	6,13,14,19,20	1,2,3,4,5,7,10,11,14,15	14	**3**
15	6,13,14,15,19,20	1,2,3,4,5,7,10,15	15	**4**
19	6,13,19,20	1,2,3,4,5,6,7,10,11,13,14,15,19,20	6,13,19,20	**1**
20	6,13,19,20	1,2,3,4,5,6,7,9,10,11,12,13,14,15,19,20	6,13,19,20	**1**

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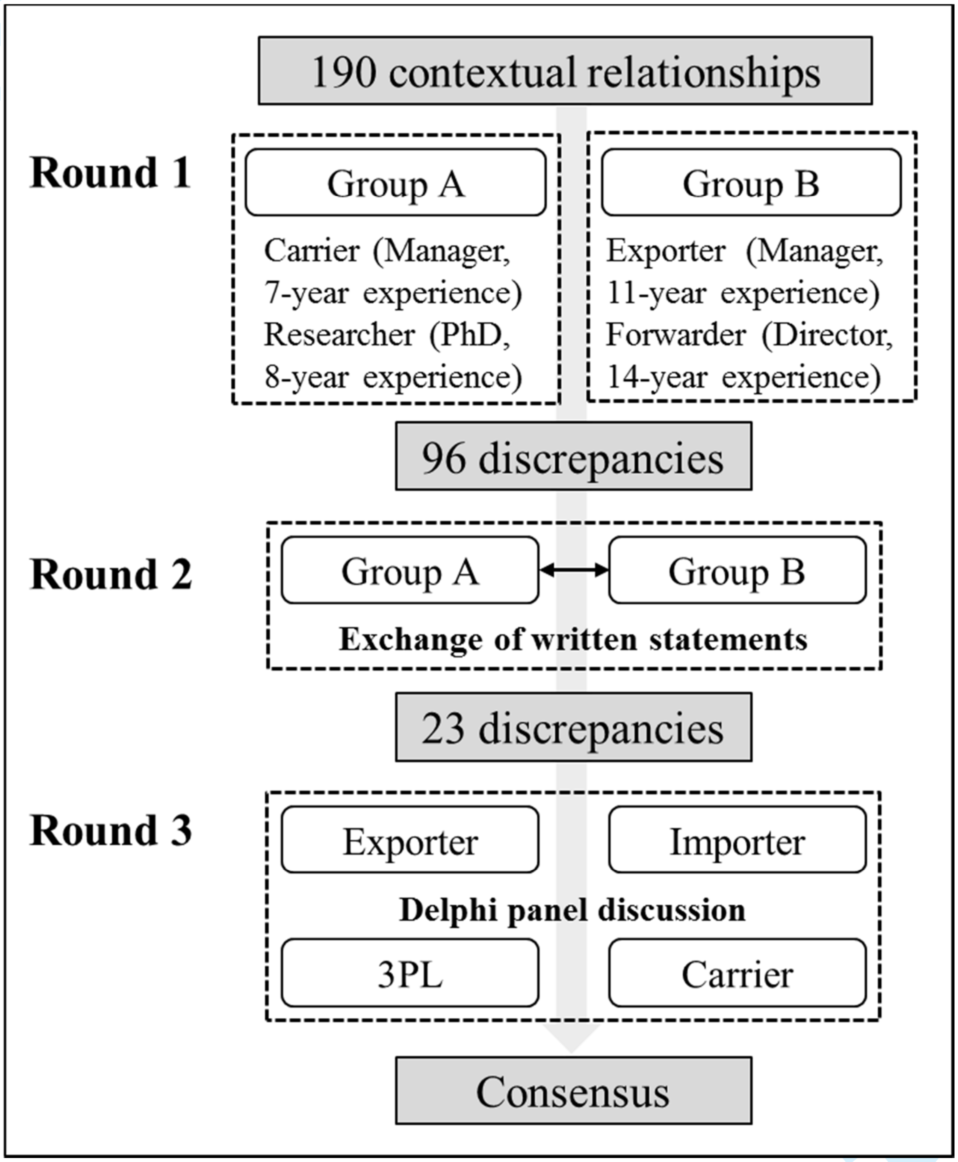
Figure 1. The Delphi Process



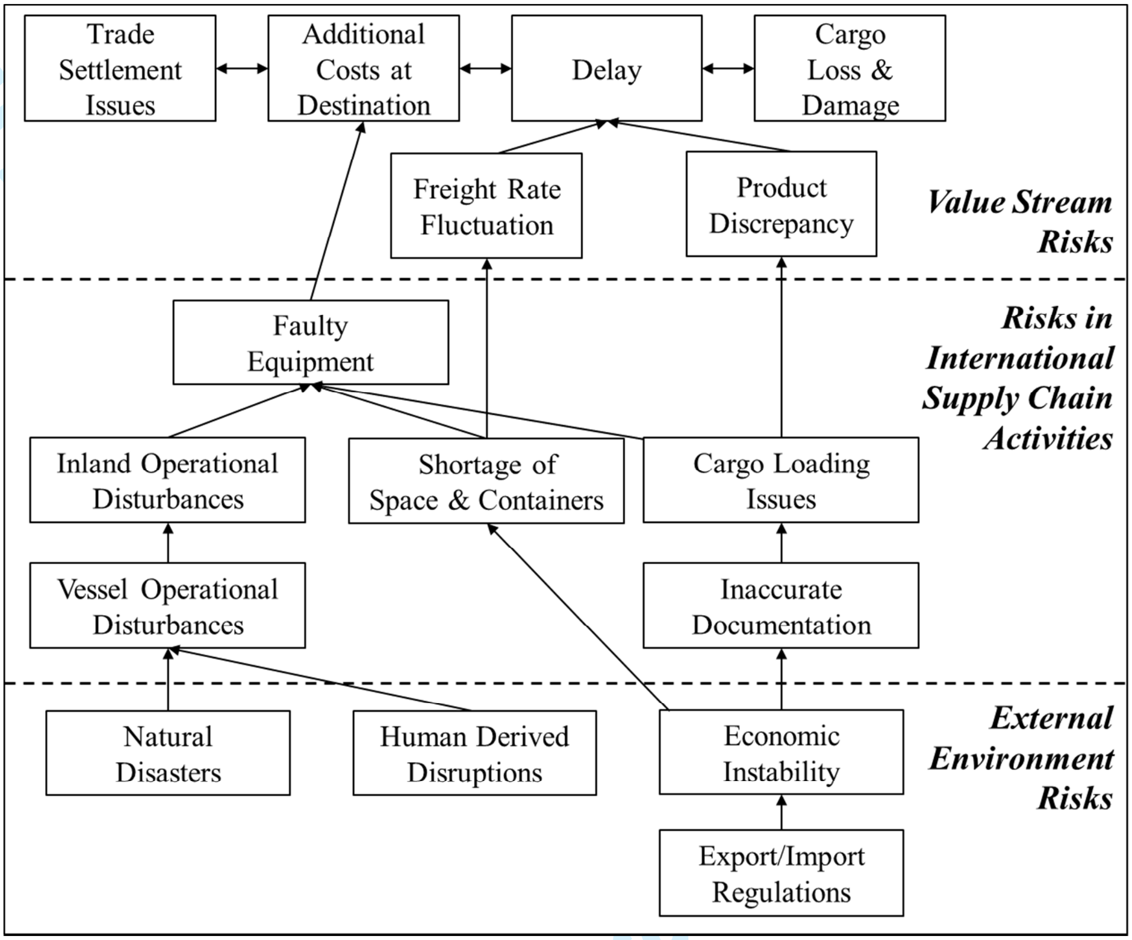


Figure 2. The ISM-based model of 16 risk elements

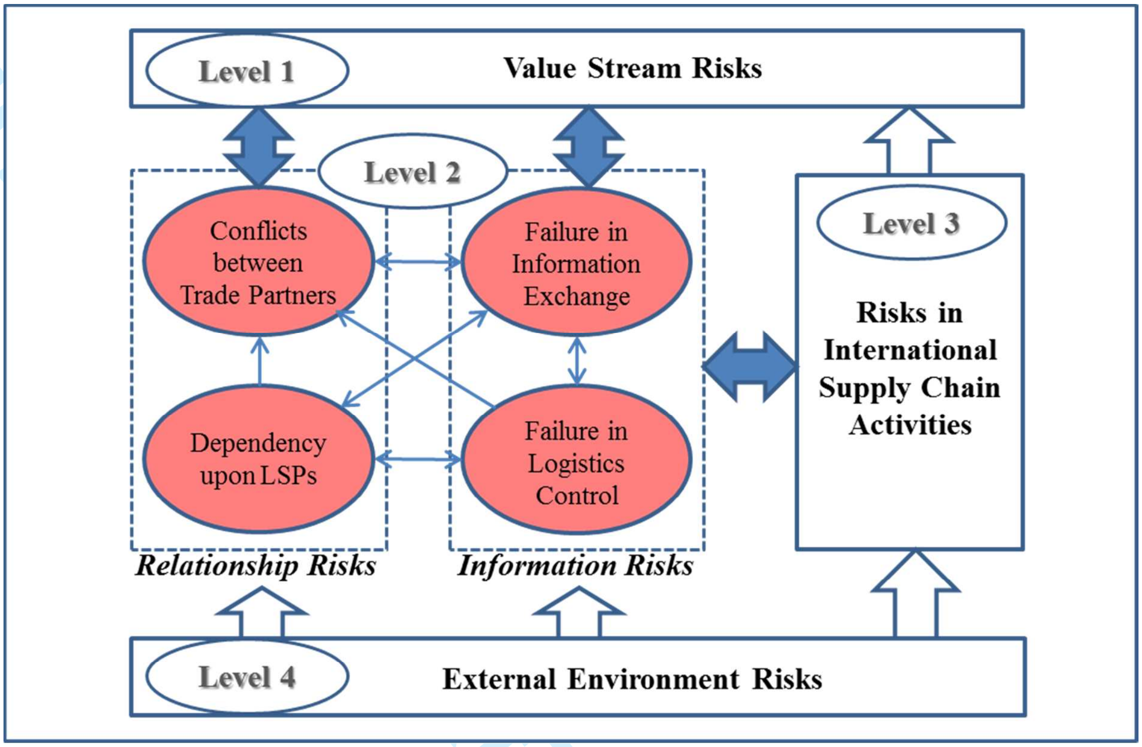


Figure 3. Risk structure centered on relationship and information risks